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Review on anti-seepage technology development of tailings pond in China

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Abstract

China is one of the countries which have the largest number of tailings ponds with the highest disaster accident rates. One of the main reasons for disaster accidents is caused by tailings seepage. It not only causes water pollution, but also generates piping effect of dam body, swamp formation and seriously even dam-break. Therefore, tailings pond anti-seepage technology is particularly important in safety management of tailings pond, which provides a technical support for design, construction and management of tailings pond and guarantee to decrease environmental pollution and disaster accidents. Technological development of tailings pond anti-seepage in China has gone through three stages (primary, intermediate and advanced), from the initial rule-less to the subsequent rule-based and laws to go by. At present, tailings pond anti-seepage technology in China has entered into a favorable development period. A variety of new materials and new technology in tailings anti-seepage have been widely applied.

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1. Introduction

China is one of the countries that have the largest number of tailings ponds with the highest disaster accident rates [1]. According to statistics, among various major disasters all around the world, tailings pond disaster ranks the 18th following nuclear explosion, earthquake, cholera, flood, etc [2]. In the case of all accidents, the destructive mudflow for dam failure will cause great damage to the life and property of downstream residents and serious pollution to the environment [3, 4]. In China, tailings ponds defined the Class 4 and above are generally classified as “major hazard installations” [5]. Therefore, tailings pond is not only one of the important production facilities of mines but also very special and important to environment protection, safety issues, and water and soil conservation.

With tailings facilities built extensively, a number of tailings dam failures have occurred in China since 1960. For example, on Oct.18, 2000, a dam-break accident occurred in Nandan, Guangxi, on Nov. 25, 2007, a dam-break accident in Haicheng, Liaoning, and on Sept. 8, 2008, a serious dam-break accident in Xiangfen, Shanxi, and so on, these accidents are still fresh in our memories. The whole country was shocked again by a tailings dam-break accident in Xinyi, Guangdong on Sept. 21, 2010. Through this tragic accident, the alarm sounded once again to people on safety of tailings pond. Actually, environment effect of tailings pond, just like safety issue, also cannot be ignored.

China has been rich in mineral resources. Currently, China has also become one of the main producers in the world in both exploitation and consumption of mineral resources. Before 2000, the total tailings discharged from mills were about 5026 million tons. After 2000, the annual tailings discharged were nearly 600 million tons [6]. As mineral resource's need is continually increasing, the volume of tailings discharged is increasing gradually. Only a small part of these tailings is applied for underground mine backfilling or other multipurpose use. Most of tailings are discharged and stored in tailings pond. Until September 2009, there were 26000 registered tailings ponds in China [7]. Besides, the number increased at a speed of 300 ponds per year.

Surprising volume of tailings directly cause environmental pollution. They mainly appear in following aspects. (1) Some tailings carry excessive pollutants, such as radioactive materials and other harmful materials. (2) Some chemical drugs in mineral processing still remain in tailings, sometime react with certain constituents in tailings to produce new pollution source. (3) Under natural exposure, the tailings undergo surface changes, such as oxidation, hydrolysis, and weathering. These cause the original nonpolluting materials to be pollutants like some heavy sulfide. This phenomenon prevalent appears in non-ferrous metal mines. (4) Water in tailings slurry discharged into tailings pond seeps into surrounding underground environment to pollute underground water system; surface water flowing through tailings pond dissolves and carries some harmful constituents by its interaction with tailings to cause pollution on a large scale [8]. (5) It is easy for tailings to be raised as dust by wind and thus to cause pollution. (6) In some remote and poor areas, some mine owners directly discharged tailings into round lakes and rivers. These actions not only pollute water body but also clog rivers, and leads to environmental disaster. (7) Due to tailings pond leaks, round environment directly polluted.

In recent years, China government is improving its environmental protect laws and regulations which make construction projects have to face higher environmental requirements than before. Therefore, tailings pond anti-seepage for environmental protection is becoming challenge to mine owners. Tailings pond anti-seepage engineering technology, as the sub-discipline of environmental geo-technology, is developed gradually to solve tailings seepage pollution scientifically.

2. Primary stage of tailings pond anti-seepage engineering technology

Anti-seepage engineering technology was only applied by few special mines in China, because at that time, tailings were usually regarded as “general industrial solid waste”. For example, uranium-bearing tailings were produced from few uranium mines and high arsenic tailings were mainly from tin concentrate upgrading plant in Geju, Yunan. In past times, the implementation of anti-seepage engineering to tailings pond was lack of relevant national regulations and standards, so in that age tailings ponds except special tailings ponds were generally constructed without any seepage control facilities. Since the 1980s, as the environmental consciousness of Chinese nationals was being strengthened and the government was paying more and more importance role to environmental protection, the environmental administration had begun to require all of tailings ponds with pollution sources be carried out with anti-seepage facilities to avoid the seepage of tailings pond which will pollute around soils and underground water. In 1985, non-ferrous metal industry firstly issued the industrial standard which was Pollution Control Standard of Solid Waste in Non-Ferrous Metal Industry (SB5085-85). It was state-owned mine enterprises which should take the lead in response to national environmental requirements. However, it is not so. For example, some state-owned aluminium plants discharge “red mud” which pH value is 11.0-11.37 that higher than standard value 6- 9. Therefore, this kind of red mud has strong corrosiveness. In addition, in some gold concentrators cyanide drugs had used for ore processing, so their discharged tailings contained toxicants. Therefore, such tailings ponds must provide with anti-seepage facilities to avoid tailings effluent from polluting environment. A tailings pond like that was called “impermeable tailings pond” at that time. However, it was lack of special anti-seepage technical standard for tailings pond. Anti-seepage materials in China were underdeveloped at that time. Tailings pond anti-seepage engineering technology then basically followed water reservoir anti-seepage standard of water conservancy and hydropower system. (In fact, tailings pond anti-seepage measures are taken especially for environmental protection and pollution prevention and different from conventional anti-seepage measures in water conservancy projects. Anti-seepage requirements for tailings pond shall be much higher than that of water conservancy projects.) Technical standard of “impermeable tailings pond” is to guarantee the leakage coefficient of tailings dam and tailings pond foundation, K , is no more than $1.0 \times 10^{-5} \text{ cm/s}$. Therefore, as long as tailings dam type was homogeneous clay dam and wet masonry rubble dam and tailings pond foundation was located as much as possible on quaternary diluvial layer or slightly weathered base rock, it was considered that the tailings pond satisfied anti-seepage requirements of environment protection. If the dam type and foundation requirements mentioned above were not met, a layer of less than 0.2mm thick home-made plastic membrane should be laid at tailings pond bottom (At that time geosynthetics above 0.75mm thick such as American GANTEL composite geomembrane was very expensive, which objectively limited its popularization and application in Chinese tailings ponds), or anti-seepage clay sloping wall was used in upstream face of dam, or vertical anti-seepage curtain was made in dam foundation to intercept leakage passage and control water leakage. In fact, even for earth-fill dam whose roller compactness was as high as 0.95, the coefficient of permeability K , was more than $1.0 \times 10^{-5} \text{ cm/s}$. In actual projects, the roller compactness of many tailings dams was only 0.92-0.94 and accordingly the coefficient of permeability K , was mostly $n \times 10^{-4} \text{ cm/s}$. As for cemented masonry dam, due to laying quality, the coefficient of permeability K , was even $n \times 10^{-3} \text{ cm/s}$. The membrane laid at pond bottom might be damaged to serious leakage. Vertical anti-seepage curtain technology was also limited to its application scope (which will state in detail in Section 4) and unfavourable to vertical leakage. Besides, mine enterprises at that time were of poor economic benefits and instinctively in conflict with the application of the anti-seepage technology because it was considered that vertical anti-seepage curtain was of high cost.

3. Intermediate stage of tailings pond anti-seepage engineering technology

During 1989-2001, the government had gradually issued lots of environmental protection regulations and standards and developed better environmental protection technologies, which made the storage and disposal of tailings as solid wastes have regulations abided by. Tailings pond anti-seepage engineering technology entered into a stage of sound progress. At this stage, environmental protection regulations and standards directly related with tailings storage and disposal are: Environmental Protection Law of the People's Republic of China (issued in 1989), Solid Waste Pollution Prevention Law of the People's Republic of China (issued in 2004), Standard for Pollution Control on the Storage and Disposal Site for General Industrial Solid Wastes (GB18599-2001) [9], and Standard for Pollution Control on the Security Landfill Site for Hazardous Wastes (GB18598-2001) [10], as well as corresponding National Catalogue of Hazardous Wastes (1998) [11], Identification Standard for Hazardous Wastes (GB5085, 1997) [12], etc.

Government departments concerned had specified that the design of tailings pond anti-seepage measure must meet the above regulations and standards. Tailings pond anti-seepage technical standard was also improved, which means the limit value of coefficient of permeability K increases from $1.0 \times 10^{-5} \text{ cm/s}$ to $1.0 \times 10^{-7} \text{ cm/s}$. The tailings pond anti-seepage standard had a significant step. The environmental protection standard was already in line with that of developed countries such as America. Specifically, the first thing was to identify tailings against national identification standards and methods and determine whether it was “hazardous waste” with hazardous characteristics or “general industrial solid waste”; the second thing was to take anti-seepage engineering technical measures in accordance with corresponding standards (GB18599-2001 or GB18598-2001) based on tailings features. At this stage, as foreign advanced geosynthetics production technology was introduced, popularized and applied in China, the home-made geosynthetic anti-seepage materials production was developed at high pace. Compared with foreign imported anti-seepage materials, home-made anti-seepage materials such as HDPE membrane, LDPE membrane, GCL anti-seepage blanket, etc. with various thicknesses were not only stable in engineering performance and reliable in laying technology, but also of competitive advantage in their costs, which could be rated as of excellent quality and reasonable price. It had objectively provided material conditions for the extension and development of tailings pond anti-seepage engineering technology. Technical Standard for Applications of Geosynthetic (GB50290-98) [13] was issued in 1998 to provide technical guidelines for the design and construction of tailings pond anti-seepage facilities. At this stage, a considerable number of tailings pond anti-seepage facilities were constructed strictly in accordance with technical standards of environmental protection.

Generally, a technical standard would undergo a process of being recognized, perfected, and developed during its implementation. Therefore, there were some inevitable “misunderstandings” for tailings pond anti-seepage engineering technology at this stage, mainly including: (1) The tailings was generally considered as “general industrial solid waste”, once they conformed with environmental protection requirements, any anti-seepage facilities need not build; (2) The effects of “horizontal anti-seepage” were surely better than that of “vertical anti-seepage”.

Up to now, the only one design code on tailings pond was issued by non-ferrous metal industry in 1991, this code is Design Code for Mine Concentrator Tailings Facilities (ZBJ1-90) [14]. However, this code mentioned nothing about tailings pond anti-seepage engineering technology. At present, Ministry of Housing and Urban-Rural Development of the People's Republic of China has been organizing experts to revise the code. It is reported that the revised new code will include a chapter of tailings pond anti-seepage engineering technology.

4. Advanced stage of tailings pond anti-seepage engineering technology

From 2001 to 2011, tailings pond anti-seepage engineering technology has been experiencing rapid development. Anti-seepage theory is being researched more and more intensively. Also, anti-seepage materials are becoming more and more developed. Construction technology is improving. Moreover, it is very good that the idea of valuing environmental protection has been accepted by people. Meanwhile, the deepening perception of tailings pond anti-seepage engineering technology has clarified two points in application area of engineering technology:

(1) Tailings pond whose tailings were “general industrial solid waste” might be installed with strict anti-seepage facilities for environment protection. According to the above-mentioned standard, tailings identified as “general industrial solid waste” should be divided into “general industrial solid waste class I” and “general industrial solid waste class II” according to Standard for Pollution Control on the Storage and Disposal Site for General Industrial Solid Wastes (GB18599-2001). Tailings pond with “general industrial solid waste class I” does not need any special anti-seepage facility for environment protection, but tailings pond with “general industrial solid waste class II” should be installed with special anti-seepage facilities for environment protection according to GB18599-2001. For example, Article 6.2.1 of GB18599-2001 stipulates that “when permeability coefficient of natural foundation layer is more than 1.0×10^{-7} cm/s, natural or artificial materials should be taken to construct anti-seepage layer whose thickness should ensure its anti-seepage performance to be the same with that of 1.5m thick clay layer with a permeability coefficient of 1.0×10^{-7} cm/s.” In actual projects, it is difficult to have natural foundation layer whose permeability coefficient is no more than 1.0×10^{-7} cm/s and thickness is no less than 1.5m. Therefore, tailings ponds requiring anti-seepage measures mostly use composite anti-seepage lining made up of single-layer anti-seepage geomembrane and clay/geosynthetic clay liner (GCL).

(2) Tailings pond using “horizontal anti-seepage” and its anti-seepage effects are not always better than that of “vertical anti-seepage”. The anti-seepage suitable for tailings pond should be selected by technical and economical comparison in combination with engineering hydrological and geological conditions of tailings pond area.

Sanitary Landfill Technology of Domestic Wastes (2004) stipulates “horizontal anti-seepage” as the only anti-seepage type of sanitary landfill. Class II tailings pond belongs to sanitary landfill. Consequently, since 2004, technical personnel of tailings pond projects and government officials of authorities gradually accept the idea to install horizontal anti-seepage facilities (mainly geomembrane liner) in tailings pond with anti-seepage requirements for environmental protection. Some tailings ponds have already installed with such geomembrane liner. However, horizontal anti-seepage mode is of certain defects and deficiencies [15]. In 1990, a detection of landfill anti-seepage laying in foreign countries indicated that even in projects of strict quality control, leakage rate of HDPE membrane reached $200 \text{ L/hm}^2 \cdot \text{d}$ [16] and the corresponding permeability coefficient was 2.3×10^{-8} cm/s, much higher than that of membrane material. Moreover, some scientific research institutions of the former Soviet Union used the method to calculate geomembrane permeability coefficient by measured leakage loss. The results showed that the permeability coefficient of 13 large-size canals with geomembrane anti-seepage was between $(2.3 - 6.1) \times 10^{-6}$ cm/s, also much higher than that of membrane material. The two examples above indicate that even though the construction quality is strictly controlled or the membrane is laid under good conditions, the anti-seepage geomembrane may have damages or holes more or less. United States and Europe countries have carried out extensive anti-seepage geomembrane detection in landfill over the past decades. China has also carried out leakage detection of anti-seepage geomembrane in landfill over recent years. The results confirm that the leakage problem caused by anti-seepage geomembrane damage in tailings pond cannot be ignored. The leaked tailings pond supernatant liquid will seriously pollute surrounding environment. In addition, the cost of geomembrane anti-seepage for tailings pond horizontal anti-seepage remains at a high level. For example, the 5th red mud pond of Aluminum Corporation of China, Henan Branch has invested CNY 125,233,000 in horizontal anti-seepage, accounting for 51.7% of

construction cost, i.e. CNY 242,211,100. The Phase 2 tailings pond of Jinfeng Gold Mine, Guizhou, has invested CNY 7,430,000 in horizontal anti-seepage, accounting for 32.2% of construction cost, i.e. CNY 23,070,000. The non-ferrous smelting slag storage site of Hulunbeir Economic Development Zone, Inner Mongolia, has invested CNY 46,130,000 in horizontal anti-seepage, accounting for 31.9% of construction cost, i.e. CNY 144,790,000. The high cost has limited the spread of the anti-seepage type. Enterprises reluctantly agree to lay geomembrane anti-seepage lining in order to pass environmental protection acceptance to maintain production. There must be a reason for the existence of vertical anti-seepage mode of tailings, mainly because of its applicability and economy in engineering practice. Only when there is impermeable layer or thick aquiclude at tailings pond bottom, it is possible to satisfy the “basic anti-seepage requirements of environmental protection” by embedding vertical anti-seepage system to a certain depth, which is the applicable condition of vertical anti-seepage mode. Compared with installing horizontal anti-seepage lining in the whole tailing pond, vertical anti-seepage system is economically advantageous in cost. Therefore, when engineering geological conditions satisfy the requirements, vertical anti-seepage structure is also one of the alternatives for tailings pond anti-seepage.

Certainly, modern detection technology can find out the damage condition of horizontal anti-seepage layer in tailings pond in time and amend it. For example, electrical leakage detection method has achieved certain effects on anti-seepage geomembrane construction damage analysis and quality assurance [17]. Some new technologies of anti-seepage should be worthy of consideration and development [18 -21].

5. Conclusions

The development of tailings pond anti-seepage technology in China has gone through three stages: primary, intermediate and advanced. At first, there was not any technical code and standard. Subsequently, regulations and laws were issued. Up to now, the standards are recognized and their application is increasingly scientific and accurate. Tailings pond anti-seepage technology has entered into a favorable development period. Many research results on tailings pond anti-seepage engineering technology have provided technical guidelines for design and construction of tailings pond anti-seepage engineering. It is important to carry out these anti-seepage technologies for reducing environmental pollution from tailings and effectively protecting the environment.

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